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(54) Improvements in and relating to generating aspheric surfaces

(57) A method of generating an aspheric surface (2) on a workpiece (1) which method comprises rotating the workpiece (1) about an axis (AA) coinciding with the required axis of symmetry of the surface (2) to be formed and applying to the workpiece (1) an annular tool (3) rotating about the axis (BB) of its annular cutting edge (4), the relative positions of the intersection of the tool and workpiece axes (BB and AA) and the intersection of the workpiece axis (AA) and tool plane in a plane common to the workpiece and tool axes being continuously variable with respect to one another in a predetermined controlled relationship whilst the tool (3) and workpiece (2) are maintained coplanar in the plane of relative movement of the said intersections.

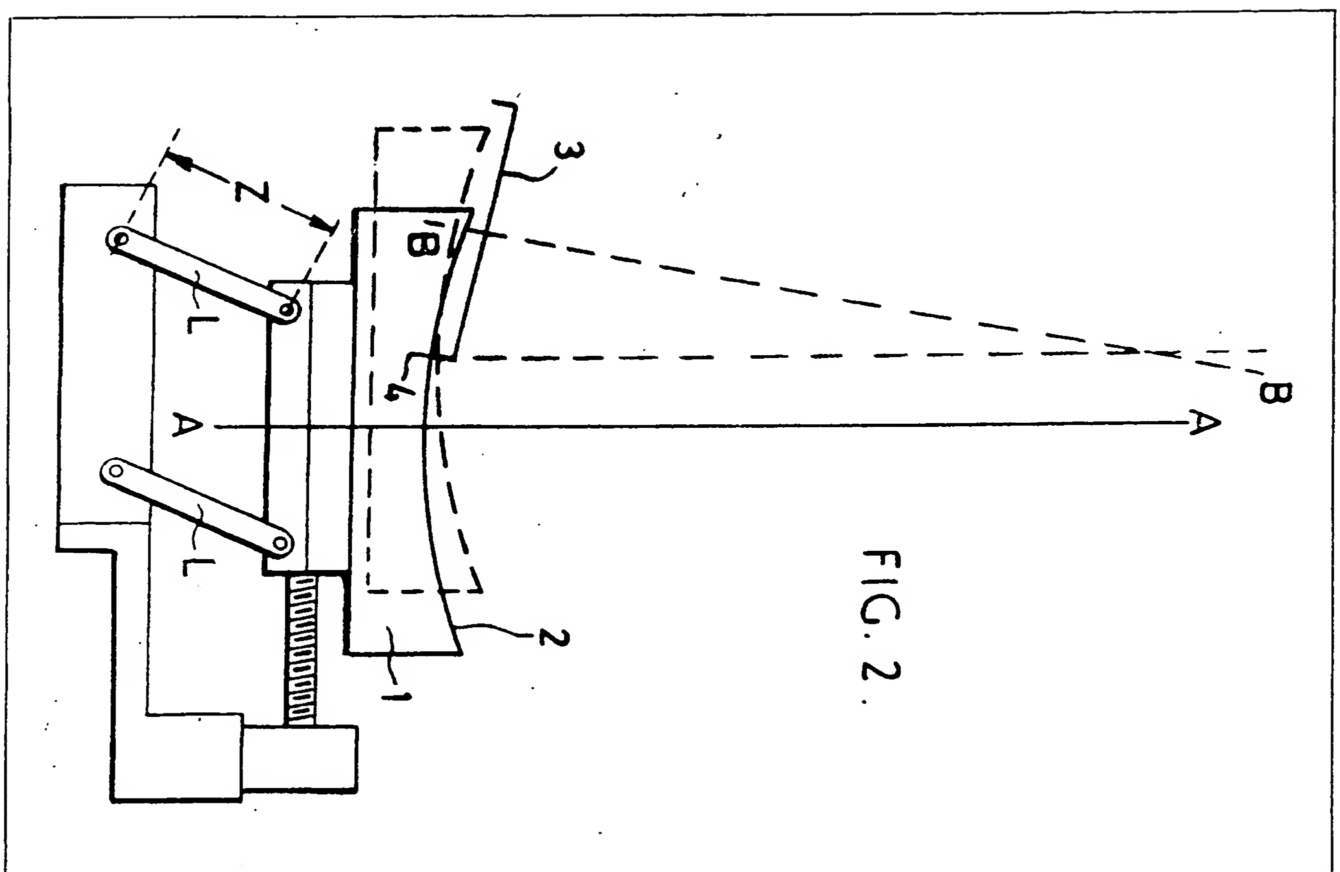

FIG. 2.

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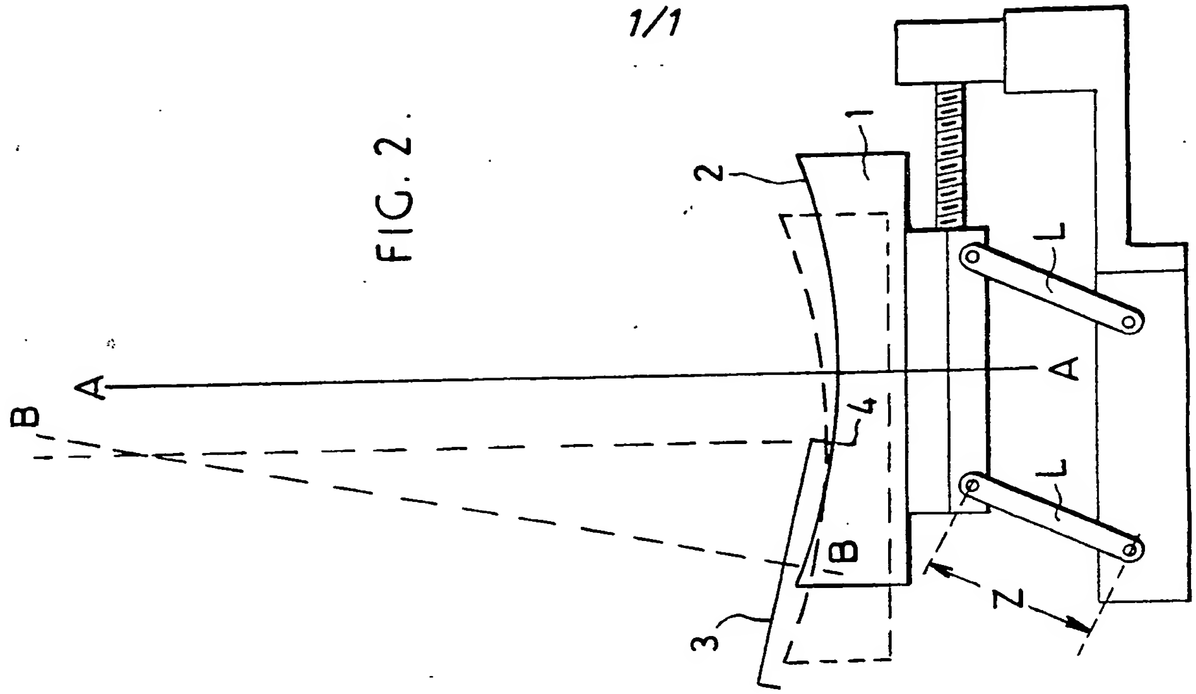

FIG. 2.

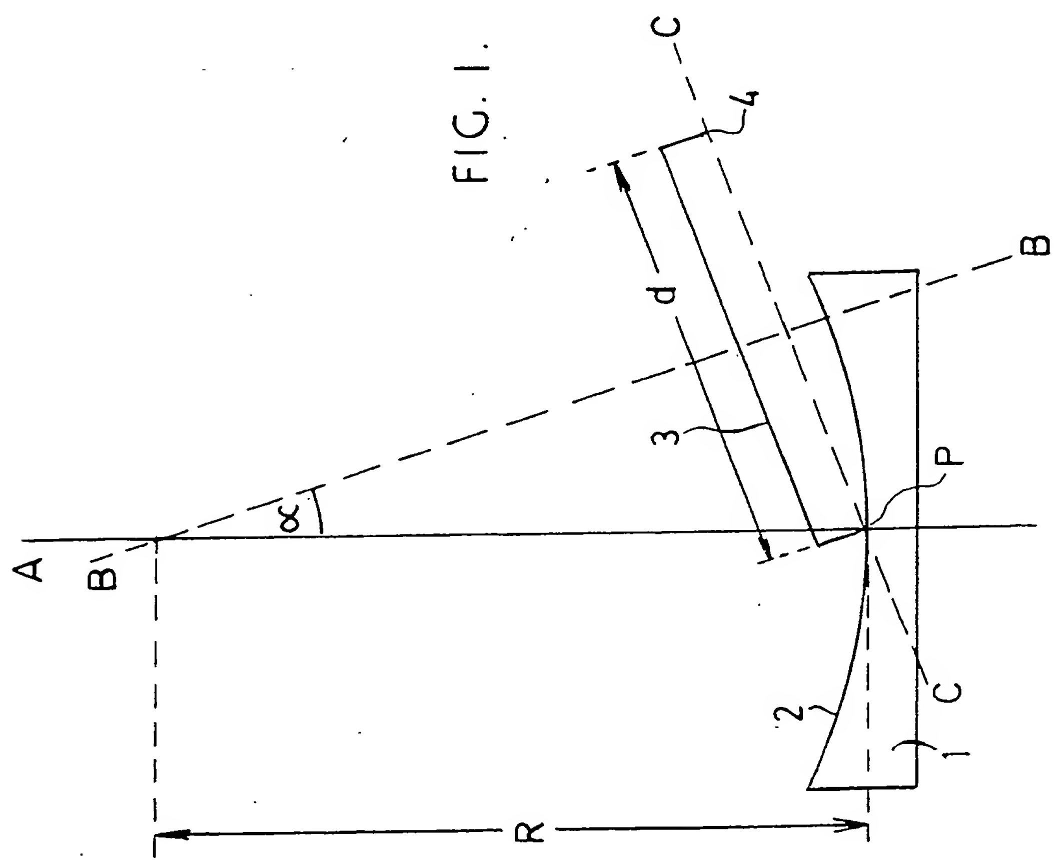

FIG. 1.

SPECIFICATION

Improvements in and relating to generating aspheric surfaces

This invention relates to generation of aspheric surfaces and is particularly applicable to generating such surfaces on optical elements.

The traditional methods of producing aspheric surfaces such as ellipsoids paraboloids and hyperboloids, on optical lenses or mirrors involves as a first step the production of spherical, or approximately spherical surface by a rough grinding process.

It is known to generate spherical curves in vitreous material by means of an annular diamond-impregnated tool, and such tools may also be used to produce an approximation to a desired concave conic surface by generating successive spherical zones. These techniques can be applied to metal surfaces by substituting a single point diamond fly cutter for the annular tool.

The object of the present invention is to provide a modification of the techniques described in the preceding paragraph whereby aspheric surfaces devoid of substantial discontinuities may be produced in vitreous or metallic materials by a single cutting process.

The present invention consists in a method of generating an aspheric surface on a workpiece which method comprises rotating the workpiece about an axis coinciding with the required axis of symmetry of the surface to be formed and applying to the workpiece an annular tool rotating about the axis of its annular cutting edge, the relative positions of the intersection of the tool and workpiece axes and the intersection of the workpiece axis and tool plane in a plane common to the workpiece and tool axes being continuously variable with respect to one another in a predetermined controlled relationship whilst the tool and workpiece are maintained coplanar in the plane of relative movement of the said intersections.

The invention further consists in apparatus for generating an aspheric surface in accordance with the method of the preceding paragraph, comprising means for rotating a workpiece about an axis coinciding with the required axis of symmetry of the surface to be formed, means for applying to the workpiece an annular tool capable of rotation about the axis of its annular cutting edge and so disposed that its axis of rotation intersects that of the workpiece, and means for providing continuous relative movement of the tool and workpiece whereby the separation between the point of intersection of the axes of the tool and workpiece and the point of intersection of the workpiece and tool plane is continuously variable.

Means may be provided to enable the workpiece axis to move transverse to its initial position relative to the cutter during generation of an aspheric surface on the workpiece whilst remaining parallel to its initial position and providing for simultaneous movement of the workpiece in the direction of its own axis.

A support table for the rotating workpiece may be mounted on a link system to move along an arcuate path in the plane of the tool and workpiece axes, or the tool may be mounted on a link system to enable it to move in an arcuate path in the plane of the tool and workpiece axes.

Means may be provided to vary the relative angle between the workpiece and cutter axes whilst simultaneously providing for movement of the workpiece or tool along its own axis.

The invention will now be further described with reference to the accompanying drawings, of which:

Figure 1 shows a diagrammatical representation of an arrangement for producing a spherical surface by means of an annular tool, and

Figure 2 shows a diagrammatical representation of apparatus embodying a modification of the arrangement shown in Fig. 1 in accordance with the present invention, whereby an aspheric surface may be produced.

Referring first to Fig. 1, a workpiece 1 to be provided with a spherical concave surface 2 is rotated about an axis A-A. A rotating annular tool 3, having a circular working edge 4 for production of the surface 2, has its axis BB inclined to the axis AA of the workpiece at an angle α. The working edge 4 may be, for example, a diamond milling edge if the workpiece 1 comprises a vitreous material, or it could alternatively be a diamond fly cutter if the workpiece is of metal. The circumferential working edge 4 of tool 3, lying in the tool plane CC, passes through the workpiece axis AA at point P.

It is evident from Fig. 1, that the following relationship holds:

$$\mathrm{SIN}\ \alpha = \frac{d}{2R},$$

where

d = diameter of annular tool

R = radius of curvature generated.

Generation of a spherical concave surface from an initially flat surface workpiece using the arrangement shown in Fig. 1 is achieved by feeding the rotating workpiece 1 upwards along its axis of rotation to the rotation tool 3.

Referring next to Fig. 2, the arrangement shown enables a smooth aspherical surface to be generated by a modification of the method shown in Fig. 1 enabling relative movement between the point of intersection of the workpiece and tool rotational axes and the intersection of the workpiece axis with the tool

plane. This relative movement in the embodiment of the invention shown in Fig. 2 comprises a transverse movement of the workpiece axis combined with movement of the workpiece along its own axis.

The relative movement required to generate a paraboloid can be expressed as an equation relating the vertical movement V required to produce contact between annular tool and the required paraboloidal surface in the presence of a transverse displacement T. Both V and T expresses the relative movement between workpiece and tool and the required relationship may be brought about by any suitable combination of movement of these.

In obtaining equations relating V to T the following symbols are used.

r radial co-ordinate on the paraboloid surface

α the angle between the axes of rotation of workpiece and tool

F the focal length of the paraboloid to be generated

β the angle between a line joining the centre of the paraboloid at radius r and the annular tool, and the tangent plane at the vertex of the paraboloid.

$$T = r^2 \tan \alpha / 4F$$

$$V = r^4 \left(\frac{4F \sin \alpha}{a \cos^2 \alpha} - 1 \right) / 64F^3$$

Hence

$$V = (T^2 / 4 \tan^2 \alpha F) \left(\frac{2 - \cos^2 \beta}{\cos^2 \beta} \right)$$

For the general case of a conic surface of eccentricity e, the relationship becomes, to a good approximation:

$$V = (T^2 / 4e^2 \tan^2 \alpha F) \left(\frac{2 - \cos^2 \beta}{\cos^2 \beta} \right)$$

By suitable choice of cutter diameter it is possible to keep $\cos \beta \sim 1$ when the relation becomes

$$V = T^2 / 4e^2 \tan^2 \alpha F$$

and using the parabolic approximation to a circular arc the required motion is along an arc of radius Z where:

$$Z = 2e^2 F \tan^2 \alpha$$

In Fig. 2 the relative movement required is produced by using a set of four links (of which two are visible in the figure) to provide a movement of the workpiece along the required circular arc, without angular displacement of its axis of rotation. Initially, with the links L set vertically, a spherical surface would first be produced by setting the tool and workpiece as described with respect to Fig. 1. Subsequent movement of the workpiece by pivoting about links L would then produce an aspheric surface closely approximating to the desired paraboloid. It will be noted that the means for axial movement of the workpiece during initial formation of the spherical surface are not shown in Fig. 2. The links must be of variable length to accommodate changes of focal length, eccentricity and tool diameter, and the workpiece and annular tool must both be rotated about their respective axes as the workpiece is slowly moved along the required arc.

A mechanism of similar type could be used to move the tool in an arc to produce the required relationship.

CLAIMS

1. A method of generating an aspheric surface one workpiece which method comprises rotating the workpiece about an axis coinciding with the required axis of symmetry of the surface to be formed and applying to the workpiece an annular tool rotating about the axis of its annular cutting edge, the relative positions of the intersection of the tool and workpiece axes and the intersection of the workpiece axis and tool plane in a plane common to the workpiece and tool axes being continuously variable with respect to one another in a predetermined controlled relationship whilst the tool and workpiece are maintained coplanar in the plane of relative movement of the said intersections.

2. Apparatus for generating an aspheric surface in accordance with Claim 1 comprising means for rotating a workpiece about an axis coinciding with the required axis of symmetry of the surface to be formed, means for applying to the workpiece an annular tool capable of rotation about the axis of its annular cutting edge and so disposed that its axis of rotation intersects that of the workpiece, and means for providing continuous relative movement of the tool and workpiece whereby the separation between the point of intersection of the axes of the tool and workpiece and the point of intersection of the workpiece and tool plane is continuously variable.

3. Apparatus as claimed in Claim 2 in which means are provided to enable the workpiece axis to move transverse to its initial position relative to the cutter during generation of an aspheric surface on the workpiece whilst remaining parallel to its initial position and providing for simultaneous movement of the workpiece in the direction of its own axis.

4. Apparatus as claimed in Claim 3 in which a support table for the rotating workpiece is mounted on a link system to move along an arcuate path in the plane of the tool and workpiece axes.

5. Apparatus as claimed in Claim 3 in which the tool is mounted on a link system to enable it to move in an arcuate path in the plane of the tool and workpiece axes.

6. Apparatus as claimed in Claim 2 in which means are provided to vary the relative angle between the workpiece and cutter axes whilst simultaneously providing for movement of the workpiece along its own axis.

7. Apparatus as claimed in Claim 2 in which means are provided to vary the relative angle between the workpiece and cutter axes whilst simultaneously providing for movement of the tool along its own axis.

8. A method of generating an aspheric surface substantially as described with reference to Fig. 2 of the accompanying drawings.

9. Apparatus for generating an aspheric surface substantially as described with reference to Fig. 2 of the accompanying drawings.

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